Measurement of the $t\bar{t}b\bar{b}$ cross section at 13 TeV

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CIEMAT

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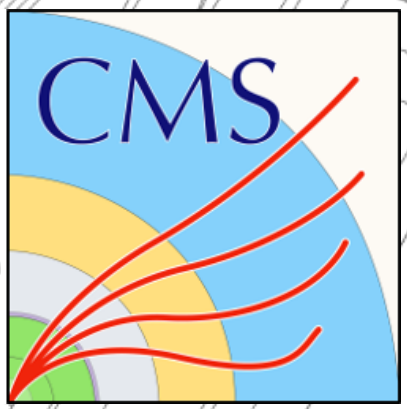
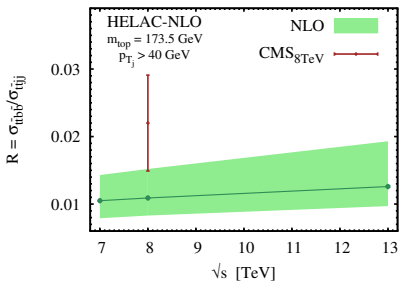
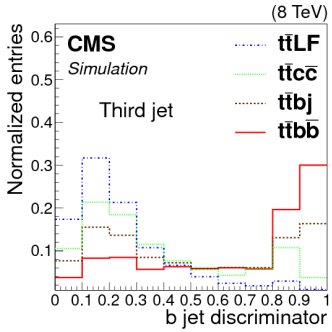


Introduction: $t\bar{t}b\bar{b}$ Production

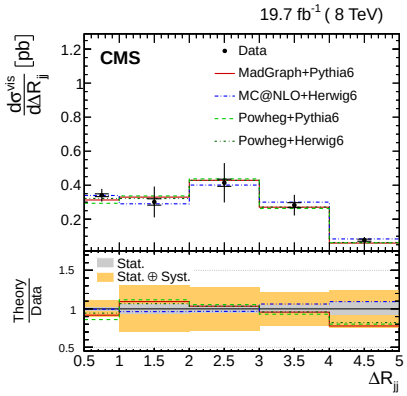
First measurements @ 8 TeV

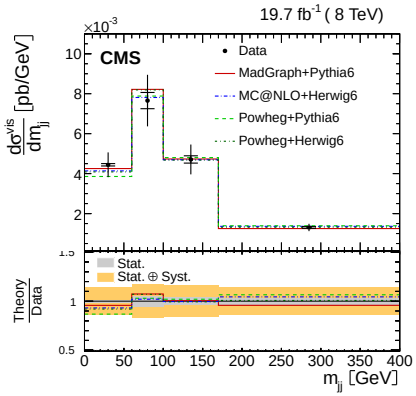
- Absolute cross section $\left(\frac{t\bar{t}b\bar{b}}{t\bar{t}jj}\right)$ PLB 746 (2015) 132



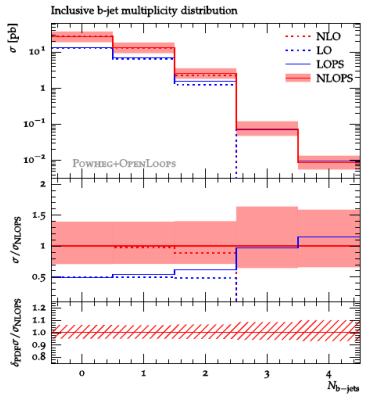


- Differential cross section EPJC 76 (2016) 379





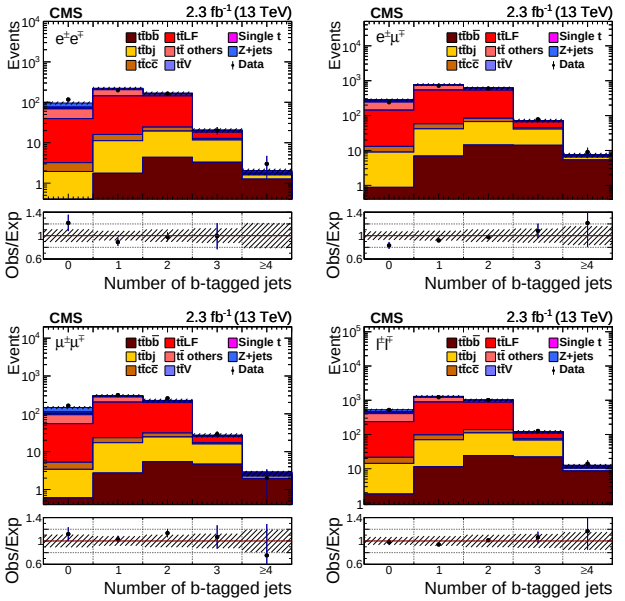
1. Direct test of the top-Yukawa coupling
2. MC generators (4F and 5F)
3. $\sigma_{t\bar{t}b\bar{b}}$ is highly sensitive to μ_R variations.

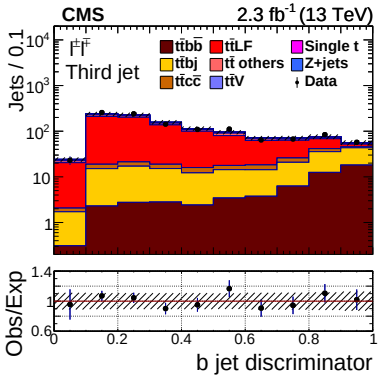


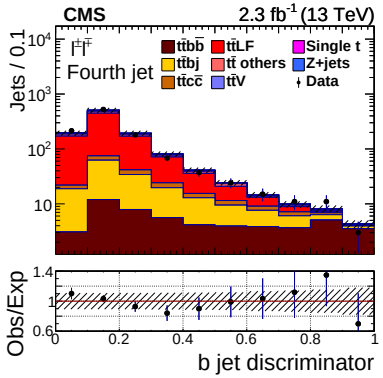
1. $t\bar{t}$ process + additional jets → additional b-jets
   - $t\bar{t}$: dileptonic (2 b-jets), semileptonic (2 b-jets + 2 jets) and full hadronic (2 b-jets + 4 jets)
   - Additional jets: b, c and LF.
2. Complex identification of the additional jets.
3. Strong object dependency:
   - Jets: Overlapping, Identification of b-jets

$t\bar{t}b\bar{b}$ and $t\bar{t}jj$ Cross Sections I

- Analysis performed with 2.3 fb^{-1} of 2015 data PLB 776 (2018) 355.
- Dilepton channel
  - Low SM background
  - limited jet combinations
- Event selection
  - 2 leptons + $\not{E}_T$ + at least 4 jets (2 b-jets)
- $t\bar{t}$ categorization (MC)
  - $t\bar{t}jj = t\bar{t}b\bar{b} + t\bar{t}bj + t\bar{t}c\bar{c} + t\bar{t}LF$
- Identification of additional jets: b-jet discriminant [0,1].
  - Jets coming from top decay tend to have a large b-jet discriminant value.



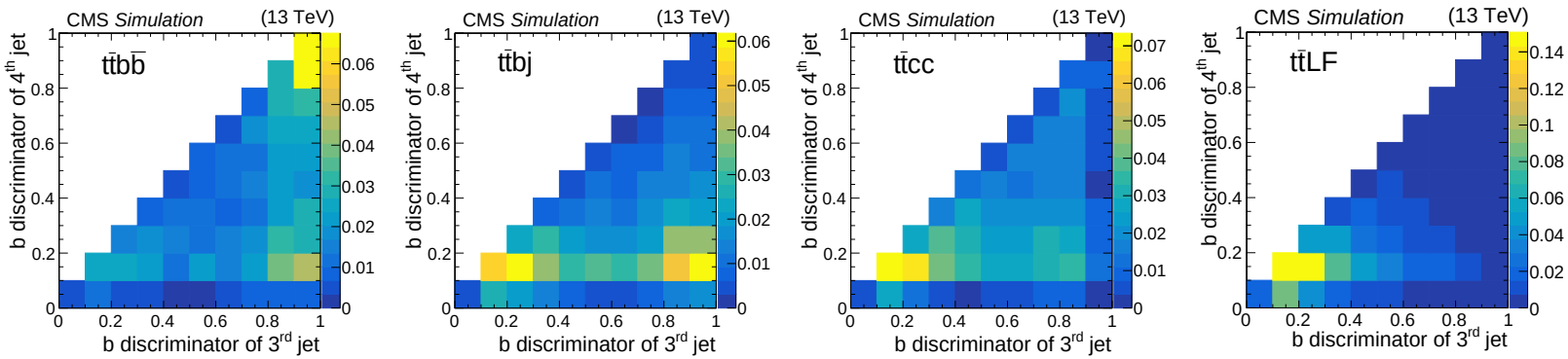




- Both jets with the highest b-jet discriminant value are consider as jet from top decay.
- 3^{rd} and 4^{th} jets are identified as the additional ones.

$t\bar{t}b\bar{b}$ and $t\bar{t}jj$ Cross Sections II

- Cross section extraction: What do we need?
  1. discriminant variable(s) to distinguish $t\bar{t}b\bar{b}$ events: b-jet discriminator of the additional jets.
  2. Reasonable approach to measure the cross section(s) keeping low uncertainties: Template fit
- Discriminant power:



- Extraction of the $t\bar{t}b\bar{b}$ and $t\bar{t}jj$ cross section ratio cancels some of systematic uncertainties → more precise measurement.
  - Simultaneous extraction of $\frac{t\bar{t}b\bar{b}}{t\bar{t}jj}$ and the absolute $t\bar{t}jj$ cross section.
  - Results provided in the VISIBLE and FULL phase space.
    - Measurement in the visible phase space reduces the model dependency!

Results: Systematic Uncertainties

- Dominated by systematic uncertainties: 34% for the $t\bar{t}b\bar{b}$ cross section
  1. Very sensitive to b-jet calibrations
  2. More precise detector corrections have been release since the publication
- Statistical uncertainty also has an important contribution
  1. The analysis is performed with *only* 2.3 fb^{-1}, this error can be significantly reduced with the full 2016/2017 data.

The larger contributions come from:

Source	$\sigma_{t\bar{t}b\bar{b}}$
Jet energy scale/resolution	7.8
b tag (b quark flavour)	19
b tag (c quark flavour)	14
b tag (light flavour)	14
MC generator	9.4
scale in particle shower	13

Phase space		$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$\sigma_{t\bar{t}jj}$ [pb]	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}}$
Visible	Measurement	$0.088 \pm 0.012 \pm 0.029$	$3.7 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
	SM (POWHEG)	0.070 ± 0.009	5.1 ± 0.5	0.014 ± 0.001
Full	Measurement	$4.0 \pm 0.6 \pm 1.3$	$184 \pm 6 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
	SM (POWHEG)	3.2 ± 0.4	257 ± 26	0.012 ± 0.001

Conclusions

1. First measurement of the $t\bar{t}b\bar{b}$ cross section at 13 TeV with data collected by the CMS detector.
2. $t\bar{t}b\bar{b}$ measurement agrees with the MC prediction from POWHEG and MADGRAPH
3. These kind of analyses are motivating many developments from theory side:
   - `POWHEG-BOX` arXiv:1802.00426
   - `Powhel(5F), Sherpa+OpenLoops` arXiv:1610.07922
4. New results coming soon!